Shielding Gas for Welding of Aluminium Alloys by TIG/MIG Welding-A Review

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Abstract:
The shielding gas is used to protect the finished weld from the effects of oxygen and nitrogen in the atmosphere. Although the weld metal properties are primarily controlled by the composition of the consumable ,the shielding gas can influence the weld's strength, ductility, toughness and corrosion resistance. In general, for a given welding wire ,the higher the oxidation potential of a shielding gas, the lower the strength and toughness of the weld. This occurs because the oxygen and carbon dioxide in the shielding gas increase the number of oxide inclusions and reduce the level of materials such as manganese and silicon in the weld metal. When welding thick aluminium sections with pure argon as the shielding gas, porosity, lack of penetration and fusion defects can occur. The addition of helium to the argon shielding gas can significantly reduce these defects. This is because the high thermal conductivity of helium results in more energy being transferred into the weld. This in turn produces a hotter weld pool, resulting in improved fusion and slower freezing times, allowing any trapped gas more time to escape. This paper deals with the detailed study of shielding gas used for aluminium welding.

Key Words: *Aluminium alloy, MIG/TIG welding,Shielding gas*

1.Introduction

Aluminium may be welded by either gas or arc processes, but arc welding is more satisfactory as the area over which the heat is generated is smaller and the speed of welding can thus be increased. The thermal conductivity of aluminium is high, being five times greater than that of steel, and hence with arc welding distortion and any tendency to crack are reduced.**[1]** Aluminum alloys are typically welded on AC with the gas tungsten arc welding (GTAW) process. Many power sources have "max penetration" indicated when more than 50% of the AC cycle is spent on electrode negative polarity and "max cleaning" when more than 50% of the cycle is on electrode positive polarity.[2] In aluminum welding hydrogen porosity is often a problem. The high stability of aluminum oxide creates an instantaneous oxide film on the wire and base metal surface. Ambient humidity reacts with the surface oxide forming chemical compounds containing water. Due to this natural process, improperly stored welding wire or non-wire brushed weld groove prior to welding may contribute to moisture in the welding arc. The moisture dissociates under the arc and hydrogen dissolves in the weld metal to create porosity upon cooling.[3] Using clean consumables and increasing weld-freezing time through modulated or interrupted spray transfer, aluminum welds have shown reduction in weld bead porosity. Experiments have also demonstrated that additions of Oxygen to Argon and Argon-Helium mixtures greatly stabilize the aluminum weld puddle permitting higher travel speeds. Fig. 1 shows the effect of additions of oxygen through the contact tip, while welding aluminum. The researchers observed a 20% improvement in travel speed. [4]While GMAW welding of high nickel alloys such as Inconel 625 and 600 series, difficulties are often encountered with the sluggishness of the weld puddle. Helium or hydrogen additions to Argon generally help, adding heat to the weld pool and improving the fluidity of the weld. Recent experimental work on micro-additions of CO_2 to Argon, Argon-Helium and Argon-Hydrogen mixtures has shown beneficial effect of stabilizing the arc [5]. Optimized micro additions of CO_2 in the ppm range improve not only the bead appearance and shape (Fig.2), but also the arc speeds.

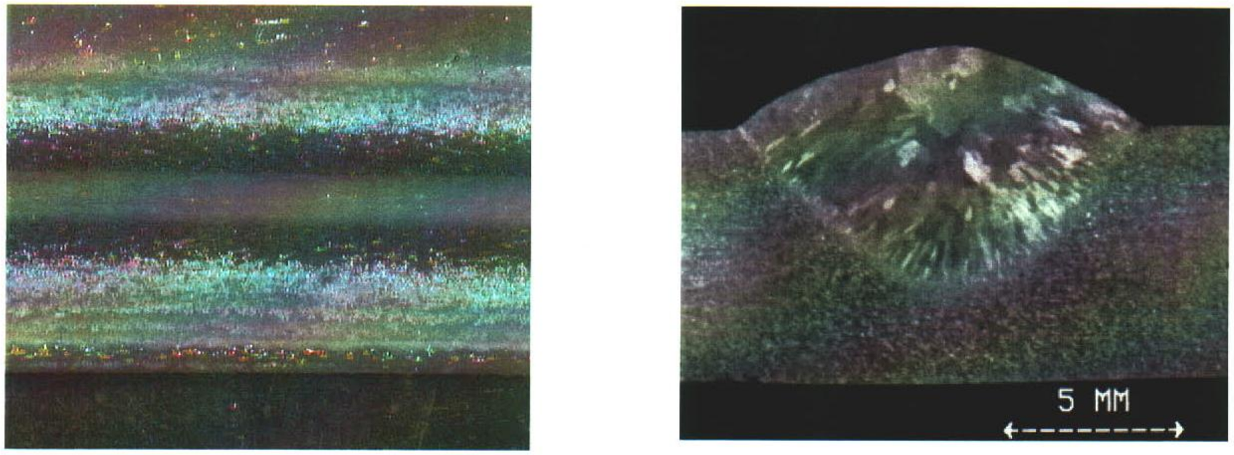

Fig. 1 -In GMAW aluminum welding, addition of oxygen to Argon shielding was shown to increase arc speeds by 20%, due to arc stabilization. In one case Argon + 1.5% 0_2 mixture was used, in another case pure Argon was used as shielding, but 0.3 uniflow of oxygen was introduced through the contact tip. The surface oxide was easy to remove by wire brushing.

Fig. 2a: Pure Argon

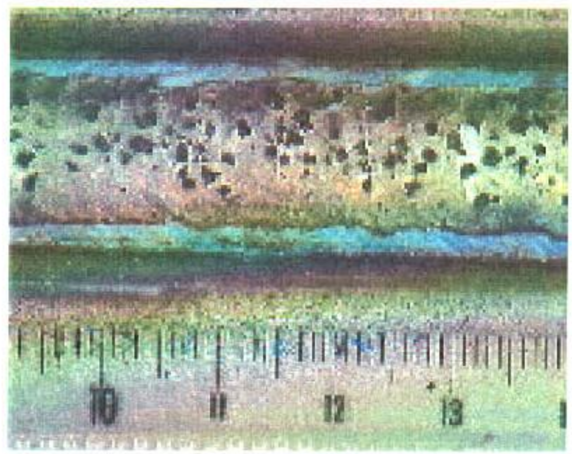

Fig. 2b: Ar+He+ $C0_2$

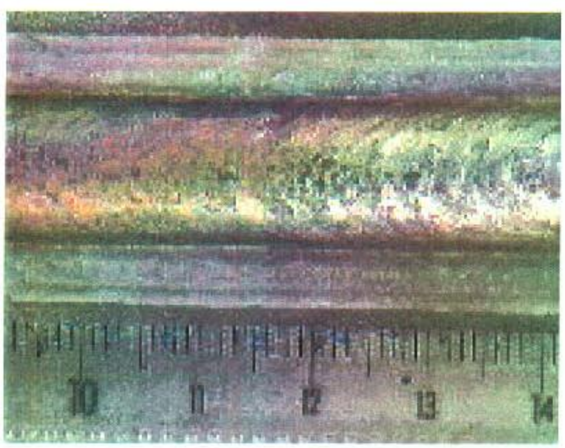

Fig. 2c: Ar+µ $C0_2$

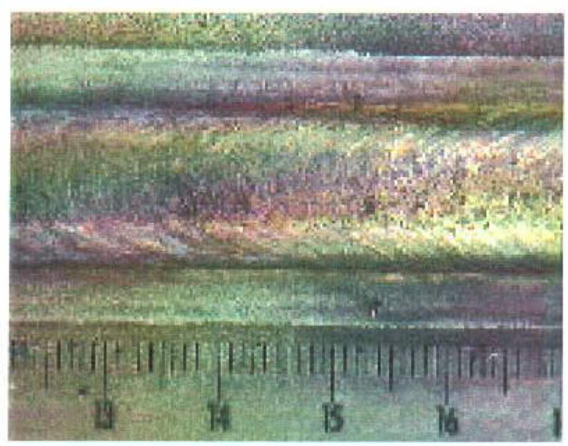

Fig. 2d: Ar+He+µ $C0_2$

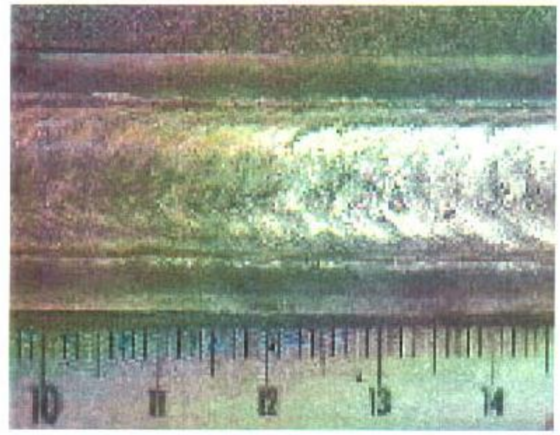

Fig. 2e: Ar+H_2+µ $C0_2$

Fig. 2 - Up to 25% improvement in arc speeds of PULSED GMAW welding of high nickel alloys, can be obtained by micro addition of C02 to Argon, Argon-Helium and Argon-Hydrogen mixtures while improving the bead appearance.

In general, the presence of inclusions is detrimental to weld properties. However, under a given set of conditions, certain oxide inclusions promote the formation of an acicular ferrite phase which improves toughness [6, 7]. On the other hand, the presence of a very high volume fraction of inclusions may initiate premature ductile fracture [8]

2.Aluminium Alloys and it's properties

Pure aluminium does not meet the demands made on modern construction materials for high yield stress and high rechrystallisation temperature, so that increase of strength is not lost at increased working temperatures and processing temperatures. It is possible to some extent to meet these demands by means of alloying and heat treatment. Mg, Cu, Si, Mn and Zn are the most important alloying elements. Other alloying elements are Fe, Ni, Cr, Co, Ti, Pb, Sb and Bi. The strength of aluminium, especially the ternary (triple) alloys Al-Cu-Mg, Al-Si-Mg and Al-Zn-Mg, can be increased considerably by means of secondary hardening.

2.1 Aluminium – physical properties

Table-1: Physical properties of aluminium

Designation of material	W. no.	Density g/cm^3	Electrical conductivity	Hardening range °C	Thermal conductivity W/cm K
Al 99,9	3.0385	2,69	35,5…37,5	660	2,39
Al 99,5	3.0285	2,70	33,5…35,5	659…658	2,26…2,29
AlMn1	3.0515	2,72	23…28	655…640	1,70…1,81
AlMg1	3.3315	2,70	24…31	655…635	1,91…2,00
AlMg3	3.3535	2,67	16…22	645…610	1,39…1,52
AlMg5	3.3555	2,66	14…19	625…590	1,20…1,34
AlMg4,5Mn	3.3547	2,70	15…19	640…575	1,20…1,30
AlMgSi0,8	3.3216	2,70	26…35	650…615	2,0…2,4
AlMgSi1	3.3211	2,70	23…26	640…595	1,63
AlZnMg1	3.4335	2,78	21…25	655..610	1,54…1,67

2.2 Aluminium typical strength properties

Table-2:Typical strength properties of aluminium

Designation of material	W. no.	Condition		Tensile strength N/mm²	0,2% tension N/mm²	Elon-gation A5 %
Al 99,9	3.0385.30	F10	hard	100		5
Al 99,5	3.0255.10		soft	70	60	6
	3.0255.26	F9	semi-hard	90	70	6
AlMn1	3.0515.26	F13	semi-hard	130	90	7
	3.0515.30	F30	hard	160	130	4
AlMg1	3.3315.30	F10	hard	160	140	4
AlMg3	3.3535.30	F26	hard	260	180	4
AlMg5	3.3555.26	F28	semi-hard	280	180	9
AlMg4,5Mn	3.3547.10		soft	280	130	17
	3.3547.07	F30	hardened	300	210	12
AlMgSi0,8	3.3216.51	F20	cold hardened	200-270	100	16
	3.2316.71	F28	warm hardened	280	200	12
AlMgSi1	3.3215.51	F21	cold hardened	210-280	110	16
	3.2315.71	F28	warm hardened	280	200	14
AlZnMg1	3.4335.10		soft	220	-	15
	3.4335.51	F32	cold hardened	320	220	12
	3.4335.71	F36	warm hardened	360	280	10

3. Welding of aluminium(Refer toDS/EN 1011 – 4 & [9])The most commonly used fusion welding processes for aluminium are:

i)MIG welding
ii) TIG welding
iii) Plasma welding

TIG and MIG welding are arc welding processes using argon as shielding gas. For special purposes it is possible to use argon/helium mixtures. It is important to bear in mind that the shielding gases must not contain hydrogen (from water) or oxygen. It is important to keep the welding free of hydrogen and oxygen which will be dissolved in the weld pool and result in pores. The oxide membrane contains moisture that turns into hydrogen and oxygen when heated. The oxide membrane must be removed in order to start welding. It cannot be melted away as its fusion point is considerably higher than the fusion point of aluminium.

3.1 The influence of hydrogen solubility

Hydrogen is the main cause of pores during the welding of aluminium. In Figure 3, the hydrogen solubility of iron is compared to that of aluminium. The significant surge in solubility when solidification takes place (at about 660ºC) and the low rate of solubility in the solid state show that hydrogen in aluminium (if the rate of cooling is too rapid) can easily be 'frozen in', thereby creating pores.**[9]** The solidification range can be considered as a yardstick for determining the formation of pores. If there is no solidification range or only a slight one, the aluminium welding deposit solidifies so rapidly that degassing cannot fully take place, thereby causing porosity. There are five main reasons for the occurrence of pores and lack of fusion in the welding of aluminium materials:

—High thermal conductivity
—Good hydrogen solubility in the molten state
— A noticeable surge in solubility when solidification occurs at about 660ºC
—Low solubility in the solid state
—No or virtually no solidification range

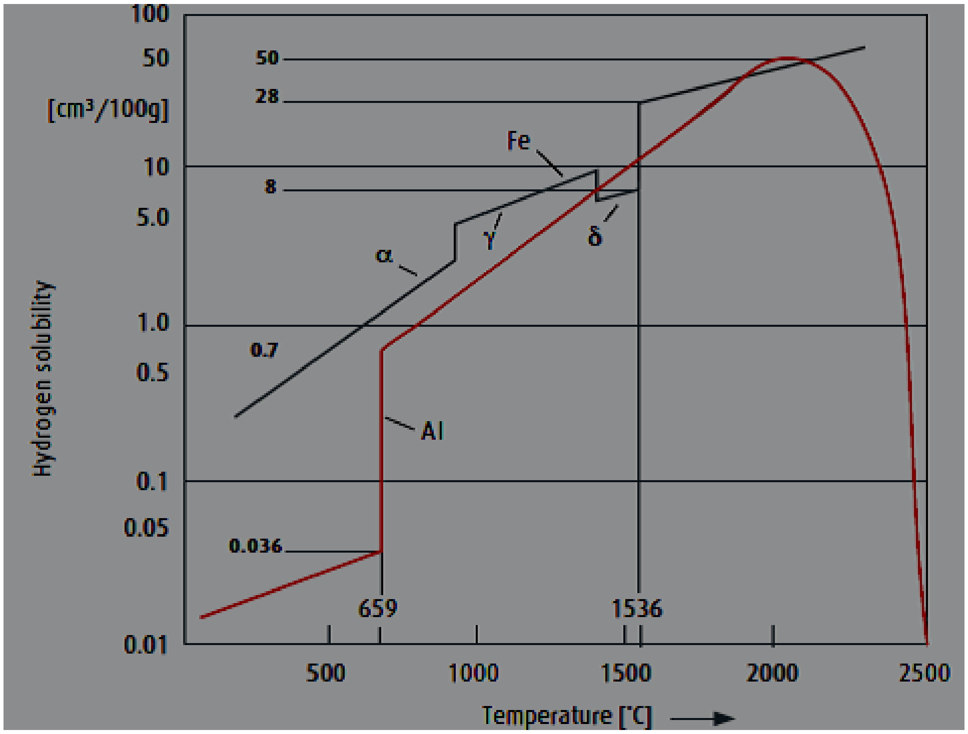

Fig.3 The hydrogen solubility of aluminium and iron.

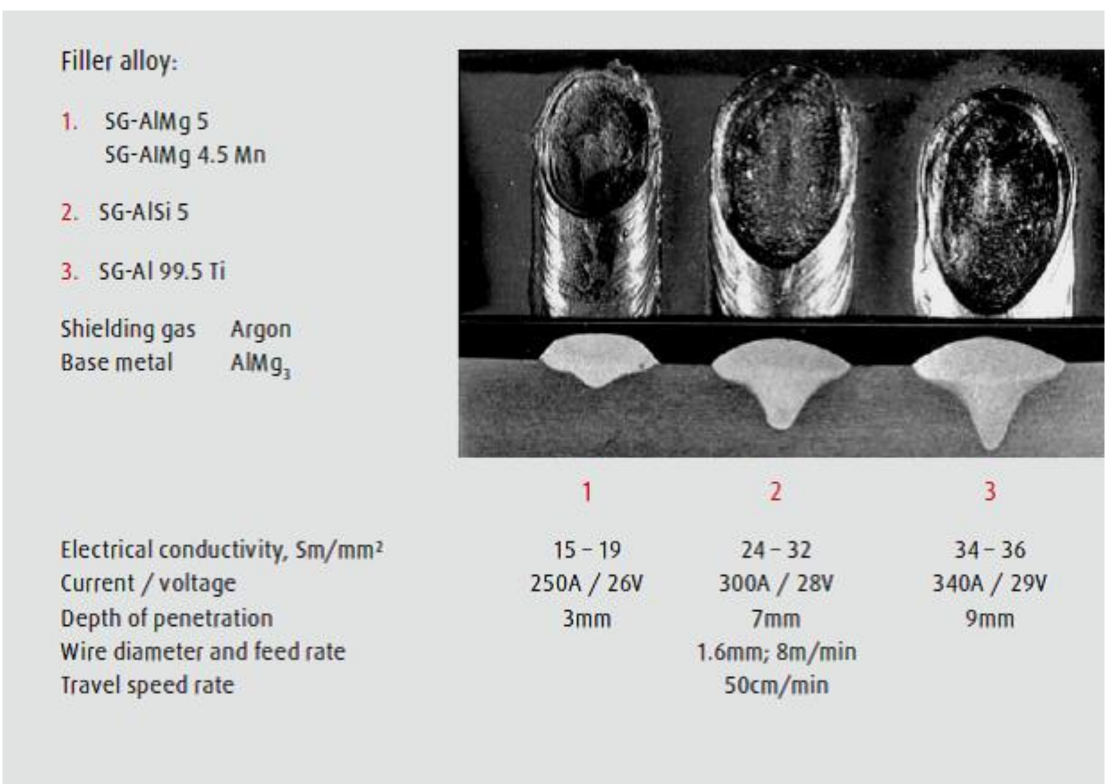

Fig. 4 MIG welding: Influence of electrical conductivity on weld geometry

3.2 The influence of electrical conductivity

The electrical conductivity of a wire electrode is basically influenced by the nature and composition of the alloy elements. The lower the alloy proportion, the better the electrical conductivity at the stick-out of the wire and the higher the welding current and voltage (with constant wire feed). This means the arc output rises, improving the weld geometry in the process (Figure 1). Changing the type of wire electrode because of the base material, therefore requires adapted set values for the wire feed (= welding current) and welding voltage.

3.3 The thermal conductivity of aluminium

Thermal conductivity of aluminium is significantly better than that of structural steel (app. 0.5W/cm.K),makes rapid welding more difficult. It also reduces the depth of penetration and leaves the melting pool with less time for solidification, thereby affecting the degassing, which can lead to lack of fusion and pores. To prevent these problems, the following should be done:

—Preheating

—Increasing the arc output

—Under certain circumstances, additional preheating during the welding of thick cross-sections

3.4 The weldability of aluminium

3.4.1 Strength analysis in aluminium welding

Table-3 Strength analysis

Hardenability	Material	Basic condition	Strength in HAZ	Possibility of increase of strength in HAZ
Not hardenable	Al99,5 – AlMn AlMgMn AlMg1..AlMg5	soft	unchanged	none
		semi-hard	reduced	none
Hardenable	AlMgSi AlSiMg	cold matured warm matured	reduced	new solution annealing and secondary hardening
	AlZnMg	cold matured warm matured	reduced	cold maturing or warm maturing

3.4.2 Filler materials

Table-4 Filler materials

Parent material	Weldability	Filler material
Al99,0…Al99,98	fine	Al99,5 – Al99,5Ti – Al99,8
AlMn0,2…AlMn1	fine	AlMn – AlMg3 – AlMg5
AlMg1…AlMg4,5…AlMg5Mn	fine until 5% Mg	AlMg3 – AlMg5
AlMgMn (e.g. AlMg4,5Mn)	fine	AlMg4,5Mn – AlMg3 – AlMg5
AlMgSi.. AlSiMg (e.g. AlSi1MgMn)	fine	AlMg3 – AlMg5 – AlSi5 – AlMg4,5Mn
AlCuMg.. AlCuMn	tendency to cracking	-
AlZnMg – AlZnMgCu	only AlZn4,5Mg1 is suitable for welding	AlMg5 - AlMg4,5Mn
AlSi5 – AlSi12	possible with Cu<1%	AlSi5 – AlSi12

There are several factors which play an important role for choosing filler materials such as analysis of parent material and it tendency to cracking during welding ,required mechanical properties of the weld, surface treatment,corrosion resistance and weldability.

4. Shielding gases

There are two shielding gases commonly used for arc welding aluminum, and these are argon and helium. These gases are used as pure argon, pure helium and various mixtures of both argon and helium. Pure argon is the most popular shielding gas and is often used for both gas metal arc and gas tungsten arc welding of aluminum.

4.1 Shielding Gas for Gas Metal Arc Welding

For GMAW the additions of helium range from around 25% helium up to 75% helium in argon. By adjusting the composition of the shielding gas, we can influence the distribution of heat to the weld. This, in turn, can influence the shape of the weld metal cross section and the speed of welding. The increase in welding speed can be substantial, and as labor costs make up a considerable amount of our overall welding costs, this can relate to a potential for significant savings. The weld metal cross section can also be of some consequence in certain applications. For a given arc length, the addition of helium to pure argon will increase the arc voltage by 2 or 3 volts. With the GMAW process, the maximum effect of the broader penetration shape is reached at around 75% helium and 25% argon.

4.2 Shielding Gas for Gas Tungsten Arc Welding

When considering the shielding gas for gas tungsten arc welding with alternating current (AC), pure argon is the most popular gas used. Pure argon will provide good arc stability, improved cleaning action, and better arc starting characteristics when AC - GTAW aluminum.Helium / argon mixtures are sometimes used for their higher heat characteristics. Gas mixtures, usually 25% helium and 75% argon are sometimes used and can help to increase travel speeds when AC - gas tungsten arc welding. Mixtures of more than 25% helium for AC – gas tungsten arc welding are used, but not often, as they can tend to produce instability, under certain circumstances.[10] The shielding gases for MIG weldingof non-ferrous metals are[11]:**Argon, VARIGON® He,MISON® Ar,MISON® He,VARIGON® S,VARIGON® He S.** Short-, spray- and pulsed arcs can be used. Besides less spatter, pulsed arcs have the advantage of allowing the use of the next largest diameter of wire electrode. The thicker the wire is, the more constant the feed rate is. The filler metals for non-ferrous materials can be found in the following standards:

- Aluminium in EN ISO 18273
- Copper in DIN 1733

The comparatively hotter arc produced by helium gas mixtures has proven to be especially suitable for materials with good thermal conductivity such as aluminium and copper. Magnesium and its alloys can be welded better using shielding gases without helium. Doping of inert gases (275 vpm NO in MISON® Ar or MISON® He and 300 vpm O_2 in the VARIGON® S series) results in improved arc stabilization for gas-shielded welding of aluminium. In contrast to MIG/MAG welding, the arc in TIG welding is generated between a non-consumable tungsten electrode and the base material. Inert gases such as argon or helium or gas mixtures with non-oxidizing components are necessary to protect the tungsten electrode and the weld pool.TIG welding can be used with all fusion-weldable metals. The choice of current, polarity and shielding gas depends on the parent material. Argon-helium mixtures promote the development of heat in the arc. Increased amounts of helium allow higher travel speeds**.[11]**

Shielding gas	Material	Comments
Argon	All weldable metals	● Most common application ● Root protection necessary for reactive materials, purity 4.8
MISON® Ar VARIGON® S MISON® He 30 VARIGON® He 30 S	Al and Al alloys	● Increased arc stability and arc starting reliability in AC welding
VARIGON® He 30 VARIGON® He 50 VARIGON® He 70 VARIGON® He 90	Al and Al alloys Cu and Cu alloys	● Additional helium for hotter arc ➜ better penetration ➜ increased travel speed
Helium		● Arc starting difficulties may occur with old power sources ➜ arc starting under argon

Table-5 **Shielding gases and materials**

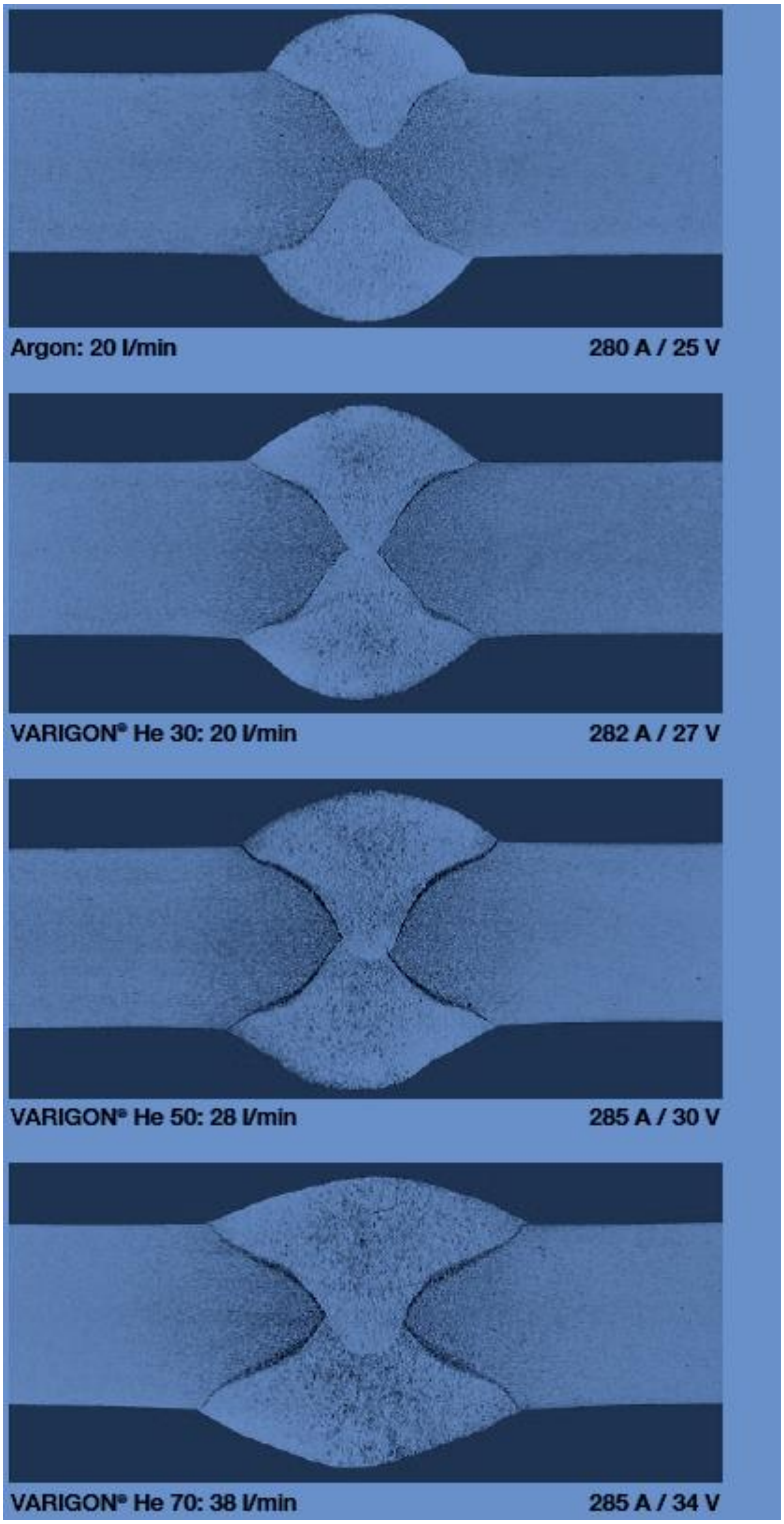

Fig. 5 Helium in the shielding gas alters the weld geometry and affects welding voltage

5. Conclusion

There are a number of choices available for gases and gas mixtures that can be used to weld aluminum. The choice is usually based on the specific application. Generally speaking, the high helium content gases are used for GMAW welding on thicker materials and GTAW welding with DCEN. Pure argon can be used for both GMAW and GTAW welding and is the most popular of the shielding gases used for aluminum. The helium content gases are usually more expensive. Helium has a lower density than argon and higher flow rates are used when welding with helium. It is possible to increase welding speeds in some circumstances by using helium and/or helium/argon mixtures. Therefore, the extra cost of the helium mixtures may be offset by your improved productivity. Hence focus should be on the different gas types and choose the one that best suits the specific application.

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